Measuring the Firmness of Cooked Apple Tissues

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Cylindrical test specimens prepared from raw apples, are evacuated, cooked, and then compressed with a Delaware jelly-strength tester. The pressure-compression curves obtained show both quantitative and qualitative differences in firmness. The compression and tensile strength of cooked tissues are inversely proportional. Certain factors which affect firmness are discussed. With slight modification, the test is applicable to the measurement of firmness of potato, carrot, cucumber and other fleshy plant tissues.

Preliminary studies on the altering of apple tissue texture by treatment with calcium salts were handicapped by the lack of a suitable instrumental method for measuring tissue firmness. Most of the previously described methods *(2)* were applicable only to raw tissues, and the use of a penetrometer on calcium treated cooked slices did not always give a true measure of firmness, especially if the slices were surface-toughened.

The method described below was designed to measure the firmness of cooked tissues. In brief, the method consists in cutting test specimens from raw tissues, and in treating, cooking, and finally compressing the specimens. With the method it is possible to detect slight changes in firmness associated with different experimental treatments.

APPARATUS

The Delaware jelly-strength tester *(1, 6)*, which is essentially a glass syringe (inverted and clamped) to which air pressure is applied at the tip for forcing out the plunger, is used to compress a cylindrical specimen (Figure 1). Air pressure is reduced to approximately 25 pounds per square inch by a reducing valve, after which its flow is regulated with a needle valve. The flow is adjusted so that the pressure on the plunger increases almost linearly with time, as indicated by a column of carbon tetrachloride (CCl_4). About 30 seconds should be required to attain a pressure of 50 cm. of CCl_4. The plunger is marked in such a manner that its movement can be measured from readings on a millimeter scale fastened to the transparent barrel. The readings are facilitated through the use of a magnifying lens and a telecentric stop *(3)*. The glass head of the plunger is ground flat. Its diameter, 21 mm., is greater than that of the test specimen. The effective weight of the plunger which compresses the specimen before air pressure is applied, is equivalent to a pressure of approximately 5 cm. of CCl_4.

PROCEDURE

The procedure is divided into two phases, the preparation and pretreatment of specimens, and the measurement of compression. In order to obtain comparable results, it is necessary to pretreat (e.g. evacuate and cook) all specimens in the same manner. The pretreatments outlined below are not necessarily optimum for other studies, but in the present case they served well.

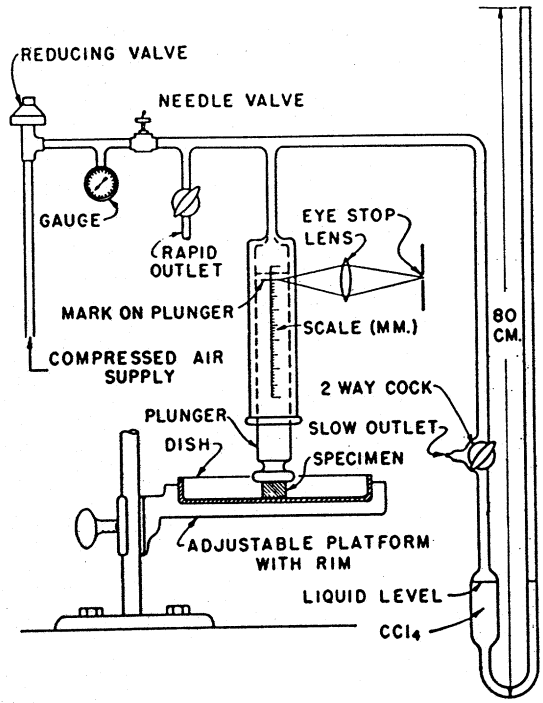

FIG. 1. Delaware jelly-strength tester as used for measuring tissue firmness. The various parts are not drawn to proportion.

To determine the firmness of cooked tissues from a fairly uniform lot of apples, seven raw apples are taken at random. If the lot is heterogeneous with respect to size and maturity, more than seven should be taken. Each apple is placed in turn with its stem-end up on a cutting block. With a long thin-bladed knife two parallel cuts about 2 cm. apart are made completely through the center of the apple from its stem end to its calyx end. The radial longitudinal slice thus formed should include both the stem and calyx. The slice is laid flat on the cutting block and from its cheek tissue, about 2 mm. inside the skin and midway between the stem and calyx, a cylinder 13.5 mm. in diameter is cut with a sharp cork borer (Figure 2). This cylinder is placed in a hole in a trimming block, which is a block of maple wood about 10 mm. thick containing a hole 13.5 mm. in diameter. Both protruding ends of the cylinder are cut off with a thin razor blade drawn flush along each surface of the block. The resulting right cylinder is approximately 10.7 mm. high. One cylinder from each of the seven apples is prepared in this manner.

The seven cylinders are placed in 100 ml. of distilled water and evacuated until they sink when the vacuum is broken. They are then boiled gently for exactly five minutes, after which they are cooled to room temperature.

A single cylinder is lifted carefully with a spatula to a petri dish fitted snugly within a recess in the platform (Figure 1) of the jelly-strength tester. The platform is adjustable either in a vertical or lateral direction. The petri dish has a flat, ground surface at its center to prevent slipping of the specimen. The specimen, resting on one of its ends, is centered beneath the manually lifted plunger, and the plunger is lowered slowly until it just touches the top of the specimen. The plunger height then is read from the millimeter scale to the nearest 0.1 mm. The plunger is released and is permitted to rest on the specimen

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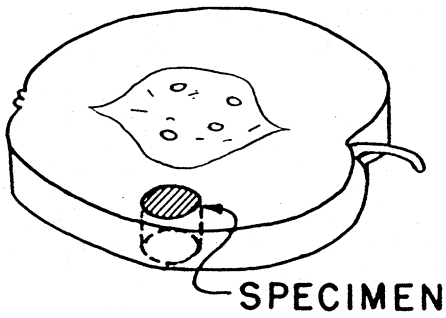

FIG. 2. Source of test specimen from radial-longitudinal slice of apple.

for 8 to 10 seconds. A second reading of the plunger height is made and immediately afterwards air pressure is applied to the plunger. The plunger height is read at pressure values of 10, 20 and 40 cm. of CCl_4.

The remaining six tissue cylinders are compressed in the same manner, and the data are averaged as shown in Table 1. If one of the specimens fails before the planned highest pressure is reached, the data on the softest specimen which remained intact is substituted for that of the collapsed specimen in the averaging. The average height of the specimens is determined from readings of the scale on the barrel made in the presence (initial test reading) and in the absence of specimens. Specimens may shrink or swell, depending upon their treatment. The average percent compression is then computed for the different pressures. The data are plotted as in Figure 3. For comparative purposes, the percent compression at a total pressure of 25 cm. of CCl_4 (equivalent to a force of about 43 grams or 0.3 g./mm²) is used to indicate the firmness of the samples (Tables 2 and 3).

TABLE 1

Representative Data on Compression of Cooked Apple Tissue

Total pressure, on specimen,[b] cm. of CCl_4	Reading of mm. scale on syringe barrel, average of seven specimens	Average net compression	
		mm.	*percent*
0	1.6 [c]		
5	2.5	0.9	8
15	3.6	2.0	19
25	4.9	3.3	31
45	6.9	5.3	50

[b] The weight of the plunger resting on the specimen was equivalent to 5 cm. of CCl_4. This has been allowed for in the pressure values listed.

[c] The scale reading in the absence of specimens was 12.3 mm. Therefore, the average height of uncompressed specimens was 12.3 — 1.6 = 10.7 mm.

RESULTS AND DISCUSSION

Reliability of Test. Uniformity in experimental material may be approached by using tissues from the same apple for different treatments. For example, six or more tissue cylinders may be prepared from each of seven apples, one cylinder from each being used for a treatment. The evacuating and infiltrating of tissues facilitate the placement of reagents near their reaction sites. Solutions of reagents such as calcium chloride, ammonium oxalate, pectase, and sucrose may be distributed more uniformly through the tissues.

The reliability of the test is indicated by the statistically treated data of Table 3, columns 2 and 3. Since the differences in firmness between lots of apples were great (compression ranged from 6 to 40 percent in the eight lots shown in Table 3), the testing of as few as seven apples from each lot often was adequate for revealing statistically significant differences. Of course, if the differences in firmness are slight, or if greater accuracy is desired, more than seven apples should be tested.

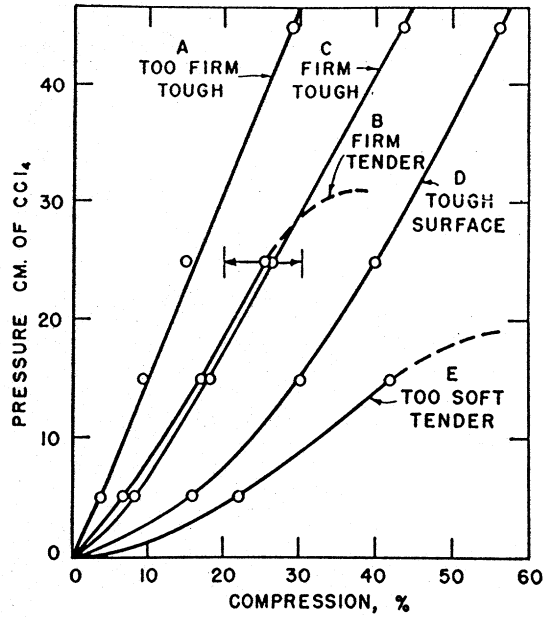

FIG. 3. Representative data showing compression of cooked apple tissues at various pressures. The curves illustrate qualitative as well as quantitative differences in firmness. Zone of optimum firmness at 25 cm. pressure is indicated by arrows through curves B and C.

Optimum Firmness. Since personal opinions are involved in estimating the most desirable degree of firmness, complete agreement on the concept is not to be expected. It is said that the consuming public objects more strongly to tissues which are too firm or tough than to those which are too soft. Furthermore, the concept of optimum firmness may vary with the maturity and variety of apple, or the concept may be influenced by differences in other characteristics of the tissues.

For the objective characterization of optimum firmness, samples were tested by the present method, by the

TABLE 2

Comparison of Objective (Compression) and Subjective Methods for Evaluating the Firmness of Cooked Apple Tissues

Sample	Method	
	Objective [d]	Subjective [e]
	Compression, percent at 25 cm. pressure	Firmness score
1	60	1
2	59	1
3	33	2
4	33	2+
5	31	2
6	27	3
7	24	3
8	22	3
9	21	4
10	17	5
11	12	4
12	11	5
13	7	5

[d] Test specimens, prepared from the raw tissues, were cooked in a boiling water bath for 20 minutes with the slices used for subjective scoring.

[e] Firmness was rated on a scale of 0 to 5, where 0 = mushy or sauce consistency, 3 = optimum firmness, and 5 = tough.

TABLE 3

Data Illustrating Relationships Among the Compression, Tensile, and Magness-Taylor Tests as Applied to Apple Tissues [f]

Apple Samples [g]	Cooked Tissues [h]			Raw Tissues
	Compression		Tensile strength, g./mm.[g]	Magness-Taylor test, pounds
	Percent at pressure of 25 cm.	Standard error		
Stayman Winesap	40	2.6	0.27	11.1
Red Delicious A	39	2.3	0.32	9.8
Jonathan A	34	2.8	0.57	10.0
Jonathan B	30	1.6	0.63	10.4
McIntosh	30	3.9	0.45	9.3
Stark	28	3.0	0.39	12.7
Red Delicious B	11	1.6	2.08	13.1
York Imperial	6	0.6	2.01	22.0

[f] The coefficient of correlation between the compression and tensile strength of cooked tissues was —0.94. The correlation coefficient between the compression of cooked tissues and the Magness-Taylor test on raw tissues was —0.81.

[g] The data do not indicate necessarily the comparative firmness of the apple varieties, but apply only to these particular samples following storage for about five months at 34° F. The York Imperial and McIntosh apples were picked at a less mature stage than were the other varieties.

[h] For the compression test of each variety, one specimen from each of seven apples was used. For the tensile test, two specimens from each of seven apples were used.

subjective method of Hills et al. *(4)*, and in some cases by a commercial pie baker. In general, tissues of optimum firmness (subjective rating) were compressed approximately 20 to 30 percent by a pressure of 25 cm. of CCl_4 (Table 2). Good agreement was obtained between the results of the instrumental and subjective methods, although the difficulty of subjectively estimating differences in firmness of comparatively firm tissues was apparent.

Qualitative Differences in Firmness. In addition to differing quantitatively in firmness, tissues may also show a qualitative difference. Equally firm tissues, as evidenced by their percent compression, may be either tough or tender. These qualitative differences are revealed in at least some cases by the present method of testing.

Tissues which are tough remain completely coherent, even though they may be compressed extensively by comparatively high pressure. After a recovery period the same tissues may be recompressed to give approximately the same result as originally. On the other hand, tender tissues collapse completely and irreversibly at only moderate pressure. In subjective terms such tissues "melt in the mouth" as the cells separate from each other and the tissues lose their continuity.

Qualitative differences in firmness are illustrated by the pressure-compression curves of Figure 3. Curves B and E show the compression of tender tissues when subjected to increasing pressure, and curves A, C and D illustrate the compression of comparatively tough tissues. The collapse of the tissues which gave curves B and E is indicated by the dashed portion of the curve. Although the tissues giving curves B and C were compressed to approximately the same extent by a pressure of 25 cm., the tissues of B collapsed when subjected to a greater pressure whereas those of C remained coherent.

A comparison of curves C and D illustrates an additional qualitative difference in firmness. The tissues of C were uniformly firm throughout their volume. In contrast, the tissues of D were surface-toughened but soft internally. In this case a slight pressure produced a comparatively large amount of compression.

Factors Affecting Firmness. Tissue firmness was affected by a number of factors which may vary either with the experimental material or with the conditions of the test. In general, there was no consistent difference in the firmness of cooked tissues from the red and green sides of a symmetrical apple. In an asymmetrical or lop-sided apple, however, tissues from the small side were on the average from 5 to 10 percent more firm than those from the large side, irrespective of the color of the two sides. Usually the small side was red. Variation in firmness of the tissue cylinders from one apple was about half as great as that of the cylinders from a group of seven apples. Cylinders cut in a radial direction (cork borer pushed from the cheek skin toward the core) were about 15 percent less firm than cylinders cut and compressed in a tangential direction, as is done in the present method.

The effect on firmness of soaking or evacuating raw tissues in water varied with the variety and maturity of apple. The soaking of fully mature tissues for three hours in some cases resulted in a 50 percent decrease in firmness. The firmness of cooked tissues varied inversely with the temperature of the tissues, cool tissues being more firm than warm tissues. In one case lowering the temperature from 60° to 25° C. (140° F. to 77° F.) increased firmness by about 20 percent. Finally, the rate of applying pressure to the tissues affected their firmness values, a slow rate giving comparatively low values. For example, with comparatively soft tissues, compression was increased about 25 percent by doubling the time required to attain a pressure of 50 cm. of CCl_4.

Correlation With Other Tests. The results obtained by three different test methods on the same apple tissues are shown in Table 3. The coefficient of correlation between the Magness-Taylor *(5)* test (firmness of raw tissues) and the compression test (firmness of tissues cooked in distilled water) was —0.81 for the samples of Table 3. These samples had been in cold storage for about five months and for the most part were of a low degree of firmness. However, in other samples, especially in freshly harvested summer or early fall varieties such as Yellow Transparent, Gravenstein, Wealthy, Williams Early Red, and McIntosh, firm raw tissues disintegrated completely when cooked in distilled water, and there was no correlation between the Magness-Taylor and compression tests. Yet if the same tissues were cooked in 0.1 percent calcium chloride solution (whose effect is similar to that of the tap water used in some processing plants), no disintegration occurred and the correlation between the two tests was good. Detailed data on the firmness of raw and cooked tissues as affected by apple variety, storage conditions, and calcium ion and other treatments, will be reported in a subsequent paper.

The compressibility and the tensile strength of the cooked tissues shown in Table 3 were inversely related, the coefficient of correlation being —0.94. The method of Personius and Sharp *(7)* was used for determining the tensile strength. Microscopic examination of the

separated surfaces of tissue dumbbells disclosed no broken cell walls. The break in the specimen was accomplished through the separation of whole, intact cells. Similar observations were recorded for tissues which were compressed beyond their breaking point. Both the tensile strength (cells pulled apart) and the compression (cells pushed together) measurements were, therefore, measurements of the strength of the middle lamella. These observations thus emphasized the importance of the intercellular cement as a determiner of tissue texture.

Testing Other Plant Tissues. The present method may be used without modification to determine the comparative firmness of other fleshy plant tissues. In most cases, however, it was advantageous to adjust the test conditions to accommodate different ranges in firmness exhibited by different tissues. This was done principally by varying the pressure, the cooking period, and the diameter of the test specimen. For tissues which usually were firm or hard, such as white potatoes, carrots, and beets, tissue cylinders 8.7 mm. in diameter and 10.7 mm. high were cut and boiled for 30 minutes. The percent compression at a pressure of 55 cm. of CCl_4 was measured. For tissues which were somewhat softer, such as cucumber, cylinders 10.0 mm. in diameter and 10.7 mm. high were prepared and tested under the same conditions as were the potatoes.

The test conditions outlined above for potatoes, carrots, beets, and cucumbers were not necessarily optimum, for only a limited number of tests were carried out. Yet the results indicated the feasibility of the test and suggested its possible application in determining such qualities as the mealiness of potato tissue.

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